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Improved Measurements of $\overline{B}^0 \to D_{sJ}^+ K^-$ decays

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Abstract

We report an improved measurement of the branching fraction for $\overline{B}^0 \to D^*_{sJ}(2317)^+K^-$ and present evidence of the $\overline{B}^0 \to D_{sJ}(2460)^+K^-$ decay. These results are obtained from a data sample containing 386 million $B\bar{B}$ pairs that was collected near the $\Upsilon(4S)$ resonance, with the Belle detector at the KEKB asymmetric energy e^+e^- collider.

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Two narrow resonances denoted as $D_{sJ}^*(2317)^+$ and $D_{sJ}(2460)^+$ have been observed recently in e^+e^- continuum interactions [1, 2, 3, 4] and in B decays [5, 6, 7]. The surprisingly low masses and small widths of these states initiated a wide theoretical discussion [8]. Although the 0^+ and 1^+ quantum numbers have been established for the $D_{sJ}^*(2317)^+$ and $D_{sJ}(2460)^+$ resonances [9], respectively, the nature of these states is still unclear.

In this paper we report an updated study of the decays $\overline{B}^0 \to D_{sJ}^+ K^-$ with a data sample that is approximately 2.5 times larger than in the recently Belle published paper [7] that first reported the $\overline{B}^0 \to D_{sJ}^*(2317)^+ K^-$ decay mode. In the previous Belle study the product branching fraction $\mathcal{B}(\overline{B}^0 \to D_{sJ}^*(2317)^+ K^-) \times \mathcal{B}(D_{sJ}^*(2317)^+ \to D_s^+\pi^0) = (5.3^{+1.5}_{-1.3} \pm 0.7 \pm 1.4) \times 10^{-5}$ was measured and an upper limit $\mathcal{B}(\overline{B}^0 \to D_{sJ}(2460)^+ K^-) \times \mathcal{B}(D_{sJ}(2460)^+ \to D_s^+\gamma) < 0.94 \times 10^{-5}$ was set. These measurements [10] show that $\mathcal{B}(\overline{B}^0 \to D_{sJ}^*(2317)^+ K^-)$ is of the same order of magnitude as $\mathcal{B}(\overline{B}^0 \to D_s^+ K^-)$ [11, 12] and at least a factor of two larger than the branching fraction for $\overline{B}^0 \to D_{sJ}(2460)^+ K^-$.

The $\overline{B}^0 \to D_{s(J)}^+ K^-$ decays can be described by a PQCD factorization W exchange process [13, 14] or, alternatively, by final state interactions [15, 16]. Assuming there is a four-quark component of the D_{sJ} mesons, the tree diagram with $s\bar{s}$ pair creation may also contribute [7]. Although accurate theoretical calculations of branching fractions are difficult for these decay modes, the experimental results disagree with the naïve expectation [17] that the ratio $\mathcal{B}(\overline{B}^0 \to D_s^+ h^-)/\mathcal{B}(\overline{B}^0 \to D_{sJ}^+ h^-)$ should be similar for $h^- = \pi^-, K^-$ or D^-.

This analysis is based on a large data sample, which contains 386 million $B\overline{B}$ pairs, collected with the Belle detector at the KEKB asymmetric-energy e^+e^- (3.5 on 8 GeV) collider [18] operating at the $\Upsilon(4S)$ resonance. The Belle detector is a large-solid-angle magnetic spectrometer that consists of a silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of aerogel threshold Čerenkov counters (ACC), a barrel-like arrangement of time-of-flight scintillation counters (TOF), and an electromagnetic calorimeter comprised of CsI(Tl) crystals (ECL) located inside a super-conducting solenoid coil that provides a 1.5 T magnetic field. An iron flux-return located outside of the coil is instrumented to detect K_L^0 mesons and to identify muons (KLM). The detector is described in detail elsewhere [19]. Two inner detector configurations were used. A 2.0 cm beampipe and a 3-layer silicon vertex detector was used for the first sample of 152 million $B\bar{B}$ pairs, while a 1.5 cm beampipe, a 4-layer silicon detector and a small-cell inner drift chamber were used to record the remaining 234 million $B\bar{B}$ pairs[20].

In this analysis we applied the same selection criteria as in [7], where a detailed description of the criteria can be found. The only differences between the two analyses arise due to the vertex detector upgrade. According to the MC simulation, minor differences in the signal widths and efficiencies are expected for the two SVD subdetector configurations, leading to respective corrections applied in the fit procedure and efficiency calculations.

Kaon and pion mass hypotheses are assigned to the charged tracks with momenta $p >$ 100 MeV/c [10] using a likelihood ratio $\mathcal{L}_{K/\pi} = \mathcal{L}_K/(\mathcal{L}_K + \mathcal{L}_\pi)$, obtained by combining information from the CDC (dE/dx), ACC, and TOF systems. We require $\mathcal{L}_{K/\pi} > 0.6$ ($\mathcal{L}_{K/\pi} < 0.6$) for kaon (pion) candidates [19].

ECL clusters with a photon-like shape and energies larger than 50 MeV, that are not associated with charged tracks, are accepted as photon candidates. Photon pairs of invariant mass within $\pm 12\,\mathrm{MeV}/c^2$ ($\sim 3\sigma$ in the π^0 mass resolution) of the π^0 mass are considered π^0 candidates; the π^0 momentum is required to be larger than $100\,\mathrm{MeV}/c$.

K_S^0 candidates are formed from $\pi^+\pi^-$ pairs with an invariant mass within $\pm 10\,\mathrm{MeV}/c^2$ ($\sim 3\sigma$) of the nominal K_S^0 mass. Invariant masses of $K^{*0} \to K^+\pi^-$ candidates are required

to be within $\pm 50\,\mathrm{MeV}/c^2$ of the nominal K^{*0} mass; those of $\phi \to K^+K^-$ candidates, within $\pm 12\,\mathrm{MeV}/c^2$ of the ϕ mass. D_s^+ mesons are reconstructed in the $\phi\pi^+$, $\overline{K}^{*0}K^+$ and $K_S^0K^+$ decay channels; a mass window of $\pm 12\,\mathrm{MeV}/c^2$ ($\sim 2.5\sigma$) is imposed in each case. The D_{sJ} mesons are reconstructed in the $D_{sJ}^*(2317)^+ \to D_s^+\pi^0$ and $D_{sJ}(2460)^+ \to D_s^+\gamma$ decay modes; within the mass difference ranges $|M(D_s^+\pi^0) - M(D_s^+) - 348.6| < 20\,\mathrm{MeV}/c^2$ and $|M(D_s^+\gamma) - M(D_s^+) - 487.9| < 30\,\mathrm{MeV}/c^2$.

Candidate $\overline{B}^0 \to D_{sJ}^+K^-$ and $D_{sJ}^-\pi^+$ are formed and the signal is extracted using the energy difference $\Delta E = E_B^{CM} - E_{\mathrm{beam}}^{CM}$ and beam-constrained mass $M_{\mathrm{bc}} = \sqrt{(E_{\mathrm{beam}}^{CM})^2 - (p_B^{CM})^2}$; E_B^{CM} and p_B^{CM} are the energy and momentum of the B candidate in the center-of-mass (CM) system and E_{beam}^{CM} is the CM beam energy. Only events within the intervals $M_{\mathrm{bc}} > 5.2\,\mathrm{GeV}/c^2$ and $|\Delta E| < 0.2\,\mathrm{GeV}$ are used in this analysis. The B meson signal region is defined by $|\Delta E| < 0.04\,\mathrm{GeV}$ and $5.272\,\mathrm{GeV}/c^2 < M_{\mathrm{bc}} < 5.288\,\mathrm{GeV}/c^2$.

Combinatorial background for channels involving the $D_{sJ}(2460)^+$ was further suppressed by requiring $\cos\theta_{D_s\gamma} < 0.7$. The helicity angle $\theta_{D_s\gamma}$ is defined as the angle between the direction opposite the B momentum and the D_s^+ momentum in the $D_s^+\gamma$ rest frame. This requirement rejects 49% of background events and only 6% of signal events, assuming $J^P = 1^+$ for the $D_{sJ}(2460)^+$. The uncertainty due to this assumption is included in the systematic error.

For events with two or more B candidates, the D_s^+ and π^0 candidates with invariant masses closest to their nominal values and the B daughter K^+ or π^- candidate with the best $\mathcal{L}_{K/\pi}$ value are chosen. No multiple entries are found in the data.

We exploit the event topology to separate $B\overline{B}$ events (spherical) from the continuum background (jetlike). The ratio of the second and zeroth Fox-Wolfram moments [21] of all particles in the event is required to be less than 0.5. For such events, we form a Fisher discriminant from six modified Fox-Wolfram moments. A signal (background) likelihood $\mathcal{L}_S$ ($\mathcal{L}_{BG}$) is obtained using signal MC (sideband) data from the product of probability density functions for the Fisher discriminant and $\cos\theta_B$, where θ_B is the B flight direction in the CM system with respect to the z axis. We require $\mathcal{R} = \mathcal{L}_S/(\mathcal{L}_S + \mathcal{L}_{BG}) > 0.4$ for $D_s^+ \to \overline{K}^{*0}K^+$ and $\mathcal{R} > 0.25$ for the other D_s^+ decay modes, which have lower backgrounds.

The ΔE and $\Delta M(D_{sJ})$ distributions for the $D_{sJ}^+K^-$ combinations are shown in Fig. 1 for the range $5.272\,\mathrm{GeV}/c^2 < M_{\mathrm{bc}} < 5.288\,\mathrm{GeV}/c^2$. To obtain the $\Delta M(D_{sJ})$ distributions we relax the $\Delta M(D_{sJ})$ requirements and apply the tight selection on ΔE. The ΔE distributions are modelled using a linear background function and a Gaussian signal shape (the Crystal Ball shape function [22] is used for the $D_{sJ}(2460)^+$) with zero mean and a fixed width determined from MC data. The $\Delta M(D_{sJ})$ distributions are described by the sum of a signal Gaussian and a linear background. The widths of the Gaussians are fixed from MC while the peak positions are allowed to float. A strong $\overline{B}^0 \to D_{sJ}^*(2317)^+K^-$ signal is observed and evidence of the $\overline{B}^0 \to D_{sJ}(2460)^+K^-$ signal is also seen. The Gaussian peak positions obtained from the fits correspond to the D_{sJ} mass values of $2319.2 \pm 1.3\,\mathrm{MeV/c^2}$ and $2456.2 \pm 6.5\,\mathrm{MeV/c^2}$ for the $D_{sJ}^*(2317)^+$ and $D_{sJ}(2460)^+$, respectively. These values are in a good agreement with the most recent BaBar measurements [23] of D_{sJ} masses in the continuum, $2318.9 \pm 0.3 \pm 0.9\,\mathrm{MeV/c^2}$ and $2459.4 \pm 0.3 \pm 1.0\,\mathrm{MeV/c^2}$.

Signal yields, efficiencies, branching fractions and significances for the studied decay channels are shown in Table 1. The signal yields are obtained from the fits of histograms shown in Fig. 1, where the three D_s decay channels are combined. The $\overline{B}^0 \to D_{sJ}^+K^-$ branching fractions and significances are obtained using a simultaneous fit to the $\Delta M(D_{sJ})$ distributions for the three D_s^+ decay channels, with independent background descriptions,

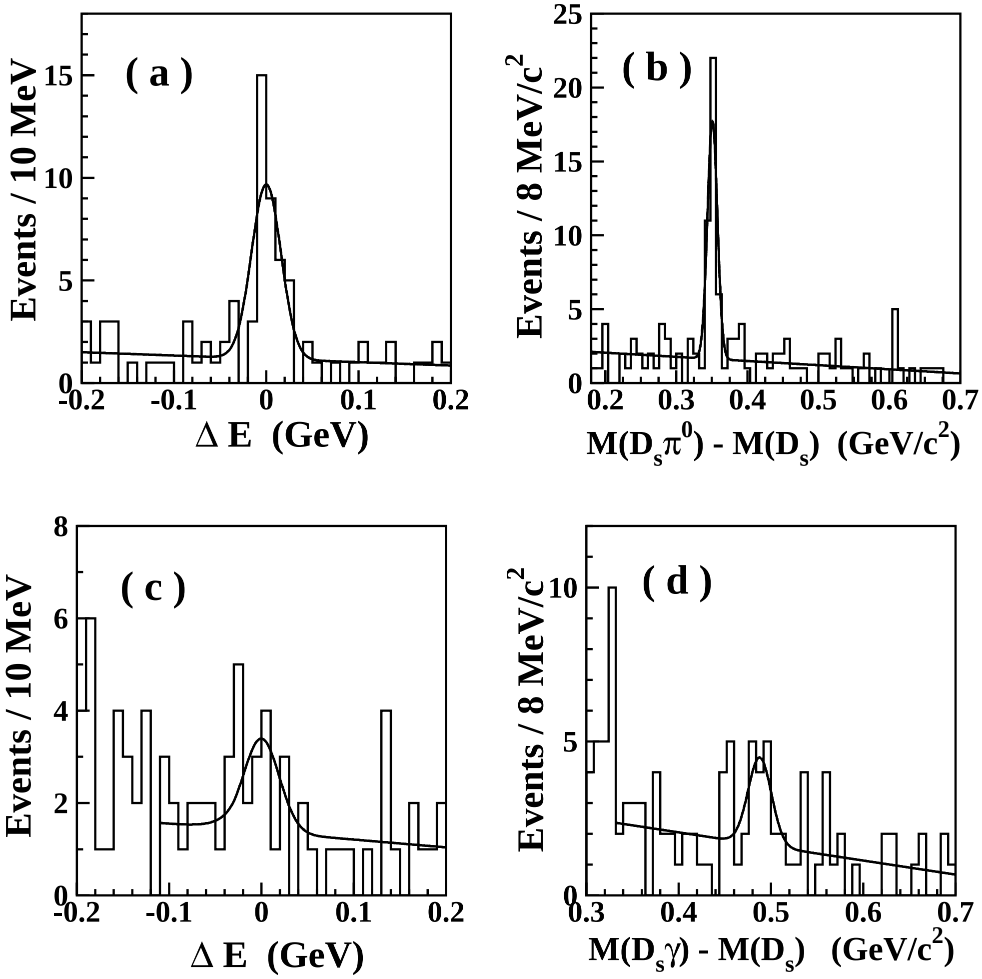

FIG. 1: ΔE (a) and $\Delta M(D_{sJ})$ (b) distributions for the $\overline{B}^0 \to D_{sJ}^*(2317)^+K^-$ decay, and ΔE (c) and $\Delta M(D_{sJ})$ (d) distributions for the $\overline{B}^0 \to D_{sJ}(2460)^+K^-$ decay.

but common values for the signal width (fixed from MC) and peak position (allowed to float). The branching fractions obtained in the individual decay modes agree within the statistical errors. The three error terms are the statistical uncertainty, the total systematic error, and the uncertainty due to D_s^+ branching fractions; this last term is dominated by the $\sim 25\%$ uncertainty in $\mathcal{B}(D_s^+ \to \phi\pi^+)$ [24]. The last two systematic terms are combined for the $\overline{B}^0 \to D_{sJ}(2460)^+K^-$ decay. The significance is defined as $\sqrt{-2\ \ln(\mathcal{L}_0/\mathcal{L}_{\rm max})}$, where $\mathcal{L}_{\rm max}$ and $\mathcal{L}_0$ are likelihoods for the best fit and zero signal yields, respectively. The significance is corrected for systematics due to the peaking background, which is estimated using ΔE and $M_{\rm bc}$ sidebands. Efficiencies include all intermediate resonance branching fractions [24] and were obtained from MC simulation, assuming $J^P = 0^+$ for the $D_{sJ}^*(2317)$ and $J^P = 1^+$ for the $D_{sJ}(2460)$. We assume equal production of neutral and charged B mesons.

The PDG value of $\mathcal{B}(D_s^+ \to \phi\pi^+) = (3.6 \pm 0.9)\%$ [24] with a 25% uncertainty is used to obtain the branching fractions listed in Table 1. BaBar has recently determined the branching fraction $\mathcal{B}(D_s^+ \to \phi\pi^+) = (4.81 \pm 0.52 \pm 0.38)\%$ [25], which has a smaller uncertainty of 13%. If we use this BaBar value the product branching fractions become $\mathcal{B}(\overline{B}^0 \to D_{sJ}^*(2317)^+K^-) \times \mathcal{B}(D_{sJ}^*(2317)^+ \to D_s^+\pi^0) = (3.3 \pm 0.6 \pm 0.7) \times 10^{-5}$ and

TABLE I: Signal yields, efficiencies, product branching fractions, and significances for the $\overline{B}^0 \to D_{sJ}^+ K^-$ processes. The first error is the statistical uncertainty, the second is the systematic uncertainty, and the third error is the uncertainty due to D_s^+ decay branching fractions. Product branching fractions are obtained from simultaneous $\Delta M(D_{sJ})$ fits of three D_s decay modes as described in the text.

Decay mode	Yield $\Delta M(D_{sJ})$	Yield ΔE	Efficiency (10^{-4})	Product $\mathcal{B}(\overline{B}^0 \to D_{sJ}^+ K^-)\times$ $\mathcal{B}(D_{sJ} \to D_s\pi^0(\gamma))$ (10^{-5})	Signif. σ
$D_{sJ}^*(2317)^+K^-$	35.3 ± 6.4	34.1 ± 6.6	21.9 ± 0.6	$4.4 \pm 0.8 \pm 0.6 \pm 1.1$	9.2
$D_{sJ}(2460)^+K^-$	11.2 ± 5.4	10.2 ± 5.4	59.5 ± 1.4	$0.53 \pm 0.20^{+0.16}_{-0.15}$	3.1
				< 0.86 (90% C.L.)	

$\mathcal{B}(\overline{B}^0 \to D_{sJ}(2460)^+K^-) \times \mathcal{B}(D_{sJ}(2460)^+ \to D_s^+\gamma) = (0.40 \pm 0.15^{+0.12}_{-0.11}) \times 10^{-5}$. The major sources contributing to the systematic error are shown in Table 2. More details about the systematic uncertainties can be found in [7].

TABLE II: Systematic uncertainties in the $\overline{B}^0 \to D_{sJ}^+ K^-$ branching fraction measurements.

Source	Systematic error (%) $D_{sJ}^*(2317)^+K^-$	Systematic error (%) $D_{sJ}(2460)^+K^-$
Track reconstruction	$\pm 1 \times N_{tracks}$	$\pm 1 \times N_{tracks}$
Charged particle identification	$\pm 2 \times N_{particles}$	$\pm 2 \times N_{particles}$
Photon and π^0 reconstruction	± 5	± 2
K_S^0 reconstruction	± 3	± 3
ΔE and likelihood ratio shapes	± 4	± 4
Helicity angular distribution assumption	± 4	$^{+9}_{-0}$
Background subtraction	± 6	± 5
Fitting procedure	± 3	± 5
MC statistics	± 2	± 2
Number of $B\bar{B}$ pairs	± 1.5	± 1.5
Total	± 14	$^{+16}_{-13}$

In conclusion, improved measurements of $\overline{B}^0 \to D_{sJ}^+ K^-$ decay modes have been performed using a data sample approximately 2.5 times larger. Good agreement with the previous measurement is obtained [7]. The value of $\mathcal{B}(\overline{B}^0 \to D_{sJ}^*(2317)^+K^-)$ is of the same order of magnitude as $\mathcal{B}(\overline{B}^0 \to D_s^+K^-)$ and significantly larger than the $\overline{B}^0 \to D_{sJ}(2460)^+K^-$ branching fraction.

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